The relationship between ring width measures and precipitation for *Widdringtonia cedarbergensis*

E.C. February* and W.D. Stock[1]

*South African Museum, P.O. Box 61, Cape Town, 8000 Republic of South Africa

[1]Department of Botany, University of Cape Town, Private Bag, Rondebosch, 7700 Republic of South Africa

Received 23 October 1997; revised 25 March 1998

Within South Africa there is a growing need for a high resolution proxy rainfall record that goes beyond the historic record. As a contribution to meeting this need the relationship between rainfall and *Widdringtonia cedarbergensis* Marsh, ring width indices is re-evaluated. As opposed to the various *Podocarpus* sp. it is possible to develop an annual ring width chronology for *Widdringtonia cedarbergensis*. In the present study, two more chronologies are added to the single chronology already available for this species. The development of these well dated ring width index chronologies is hampered by a lack of an abrupt termination of late wood growth in many of the trees utilised for this study. Despite this limitation the results show that with a large enough sample size it is possible to develop well-dated ring width indices from *Widdringtonia cedarbergensis*. Correlations between ring width indices and rainfall are not sufficiently high to reconstruct rainfall through time.

Keywords: Dendrochronology, *Widdringtonia cedarbergensis*, rainfall reconstruction.

*To whom correspondence should be addressed.

Introduction

The Southern Hemisphere has very few available instrumental and historical climate records when compared to the Northern Hemisphere and South Africa has no high resolution climate series that extends back in time for more than 100 years. Tree ring records from South America have proved useful for almost 4000 years of temperature and precipitation reconstruction (Lara & Villalba 1993) and similar results have been recorded from Tasmania (Cook *et al.* 1992) and New Zealand (Norton *et al.* 1989). South Africa presents more problems in the application of dendrochronological studies than any other region in the Southem Hemisphere, primarily because of poorly defined, locally absent and converging rings. These problems have been dealt with extensively in the publications of the Climatology Research Group at the University of Witwatersrand (Lilly 1977; Curtis *et al.* 1978; McNaughton & Tyson 1979; Dyer 1982; Tyson 1986).

The work of the Climatology Research Group especially that of Lilly (1977) has, however, focused dendrochronological research in South Africa on two species of *Podocarpus*. As a result of this research there has been very little progress in finding species that are more suitable for denrochronology. Dunwiddie and La Marche (1980) have successfully developed a chronology for *Widdringtonia cedarbergensis*. This chronology at a site called 'Die Bos', in the Cedarberg Mountains near Cape Town (Figure 1), is the only dated annual ring width chronology available for a South African indigenous species. However, Dunwiddie and La Marche (1980) were not able to establish a direct correlation between their ring width index chronology and rainfall or temperature. Rather, they could only tentatively interpret their chronology as a record of spring and early summer moisture availability. In a re-evaluation of the Dunwiddie and La Marche (1980) data set, Zucchini and Hiemstra (1983) concluded that although significanL at the 1% level the correlation between the transformed ring width indices and rainfall records from the nearest weather station at Wupperthal was not sufficient to reconstruct rainfall patterns since only 22% of the variability in transformed ring width indices could be attributed to rainfall.

Zucchini and Hiemstra (1983) concluded that a rain gauge closer to the 'Die Bos' site may well have resulted in a better correlation between their ring width index chronology and rainfall. Based on this conclusion the research described in the present paper uses *W. cedarbergensis* from two separate localities in the Cedarberg which were specifically chosen because of their proximity to rain gauges. If proximity to a rain gauge is the major factor preventing a significant correlation between rainfall and ring width index then the results of the present study should indicate whether a ring width index chronology of *W. cedarbergensis* can be used in climate reconstruction in southern Africa.

Methods

In accordance with the suggestion by Zucchini and Hiemstra (1983) the trees selected for this study were situated close to a rain gauge. Rainfall records for Algeria are available from 1900 to 1994 and are collected approximately 1500 m from the location of the trees. The nearest reasonable rainfall record to Krakadouw is located approximately 5 km away, at Wupperthal, with data available from 1898 to September 1977. These two data sets are ideally situated to explore more fully the relationship between ring width index chronologies of *W. cedarbergensis* and rainfall. Unfortunately, there are no temperature records within close proximity (100 kms) to the sites so that the relationship between ring width measures and temperature could not be fully explored. *W. cedarbergensis* grows in an environment in which rainfall is severely limited during the hot summer months. Therefore, in the Cedarberg mountains, it is rainfall that is the major limitation to plant growth.

Increment borer samples of *W. cedarbergensis* were collected in February 1995 from 10 trees at Algeria (32°22': 19°04') in the southern Cedarberg and 12 trees at Krakadonw (32°13': 19°04') in the northern Cedarberg (Figure 1). At Algeria these samples were supplemented by a further 5 radial discs cut from living trees in May 1995 as well as 11 discs collected by La Marche and Dunwiddie in 1976 and 1978. Radial cross sections were also collected from 9 trees killed in a fire at the Krakadouw site in January of 1995. The Algeria sample came from a plantation that had been planted *circa* 1910 at an altitude of 600 m in the southern Cedarberg, while the Krakadouw sample had been planted *circa* 1900 in the northern Cedarberg at an altitude of 1000 m. The climate at these sites is classified as Mediterranean with definite winter rainfall between June and August of between 500 and 900 mm at Algeria and 200 to 300 mm at Krakadouw. Summers are hot and dry with rainfall averaging around 20 mm at Algeria and 5 mm at Krakadonw. The distance between the two sites, as the crow flies, is approximately 17 km.

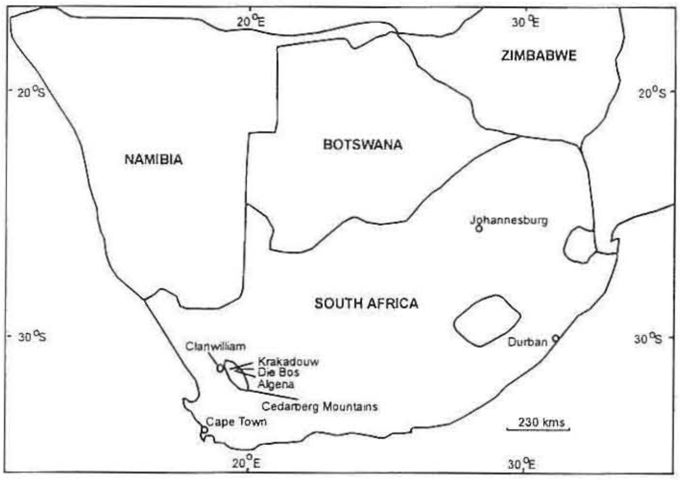

Figure 1 Map showing the location of the Cedarberg Mountains in South Africa and the sites from which samples of *W. cedarbergensis* were collected.

Clanwilliam which is approximately 26 km from Algeria and 15 km from Krakadouw at an altitude of 152 m has a mean maximum temperature of 27°C and minimum of 12°C.

In the laboratory, a belt sander (4" Makita, Japan) was used to prepare the surface of the cores and discs for microscopy. Ring widths were measured with a computer linked (Bannister model, America) Henson incremental measurement machine in conjunction with a Bausch and Lomb (Germany) stereoscopic microscope with cross hairs, normally at 15× to 30× magnification (Robinson & Evans 1980). Cross-dating following the technique described by Stokes and Smiley (1968) was extremely difficult and not always successful. As a result, a refinement on this technique was adopted, whereby rings were first measured and then cross-dating was verified and corrected with the computer programme COFECHA (Holmes 1983).

Cross-dated series were selected for high sensitivity and high correlation with the adjusted master series. The computer programme ARSTAN (Cook 1985) was used to develop a chronology from each of the two localities. Ring widths were de-trended into dimensionless indices to remove the effects of changes in tree growth that result from ageing as well as to homogenise the mean and variance and to produce a standard chronology for the site suitable for climate reconstruction (Cook 1985). Climatic interpretation of the two chronologies was based on the relationship between ring width indices and available regional precipitation records for the rainfall stations at Algeria and Wupperthal. These relations were investigated using correlation functions for various combinations of monthly and seasonal precipitation from 1919 to 1994 for Algeria and from 1898 to 1977 for Krakadouw.

Results

Of the 24 cores and 9 discs (21 trees) from Krakadouw only 22 radii (17 radii from discs and 5 from cores) from 11 trees were successfully cross-dated (Figure 2 illustrates cross-dating). The oldest tree at Krakadouw was 99 years old which is very close to the approximate date of planting, 1898. Of the 16 discs and 20 cores (26 trees) collected from Algeria only 25 radii (19 radii from discs and 6 from cores) from 14 trees were successfully cross-dated. The oldest trees at Algeria date to 1918/1919. It is possible that about 4 years of growth are missing from the collected discs indicating a good correlation between actual age and ring count age. Those samples which could not be cross-dated were rejected because of several growth features which make cross-dating in this species extremely difficult. Within the *Podocarpus* species lobate growth and especially wedging out of growth rings make cross-dating an impossible task. These two features are not common in *Widdringtonia*. What is common is a lack of definition of the end of the growing season (Figure 3) which can often only be properly ascertained by carefully tracing the circumference of the ring on a cross section (Curtis *et al* 1978). Cross-dating is further complicated by false rings and resin filled bands of cells which are often more clearly defined than the actual growth ring (Figure 3). Ill defined termination of late wood growth was extremely common among the samples from Algeria, whilst being very rare in those samples from Krakadouw. This meant that it was possible to cross-date all the discs (nine) cut at Krakadouw while at Algeria six discs of a potential 16 did not cross-date because of lack of definition in ring structure.

Using the computer programme ARSTAN (International Tree Ring Data Base) a chronology was built using 22 selected ring width series from 11 trees at Krakadouw (Figure 4) and 25 series of 14 trees from Algeria (Figure 4). These chronologies were correlated with rainfall figures from Algeria and Wupperthal. The result of the correlation coefficient analysis of average annual rainfall and ring width index chronology for Algeria shows that the trees at this site are less sensitive to rainfall ($R = 0.06$, NS) than those at Krakadouw ($R = 0.48$, $P<0.001$). There is a strong positive correlation between rainfall values from the two sites ($R = 0.75$, $P < 0.001$) with no significant correlation between ring width indices ($P < 0.05$).

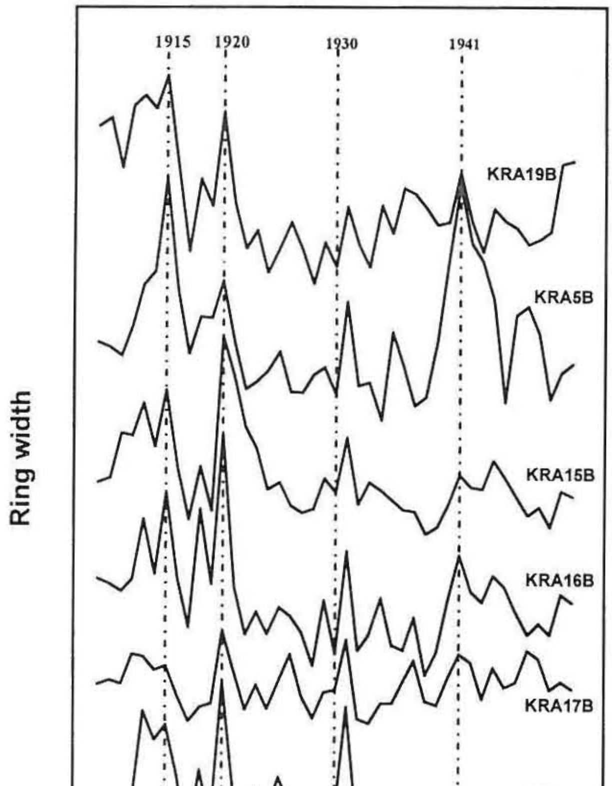

Figure 2 Portions of ring width plots for six trees that form part of the Krakadouw site chronology illustrating cross-dating in the period 1910–1950.

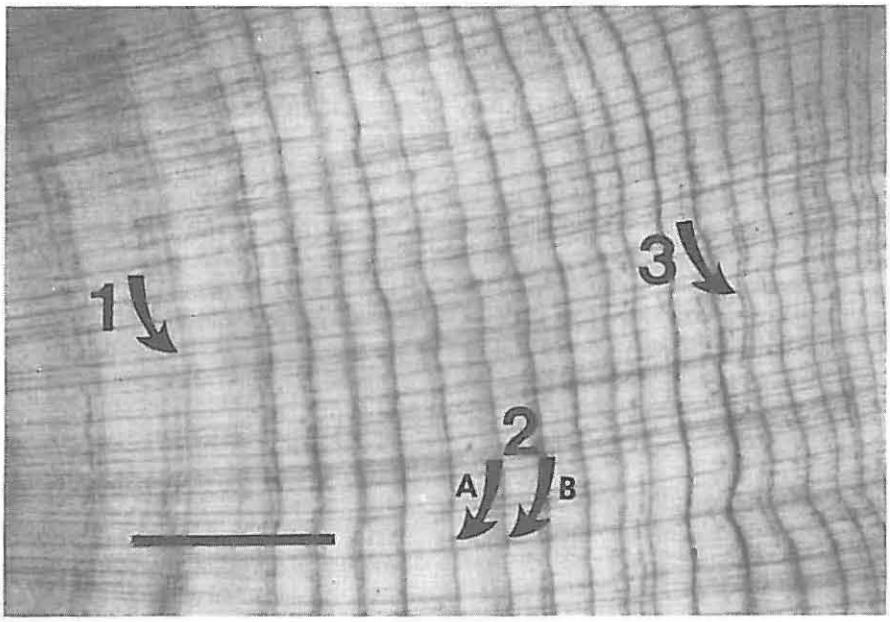

Figure 3 Photomicrograph of a transverse section of *W. cedarbergensis* showing:
1. Lack of definition in ring boundaries,
2. Clear definition of ring boundary showing both start (A) and end (B) of growing season,
3. False ring formed by a band of resin filled cells. Scale Bar = 5 mm

Discussion

Unlike the many North American and European trees used for dendrochronology most South African woody species are not suitable for such purposes (Lilly 1977). Differing from the various *Podocarpus* species, circuit uniformity of *Widdringtonia cedarbergensis* is usually good, with lobate growth and wedging out of individual rings being uncommon. There is also a good approximation between age determination through ring counts and actual age of the trees. However, Dunwiddie and La Marche (1980) sampled 46 trees (58 cores and 25 discs) but only 32 trees (52 radii) make up their final chronology. This means that 30% of the trees sampled by them were found to be unsuitable for dendrochronological analysis. In the present study, 48% of the trees sampled at Krakadouw and 46% of those sampled at Algeria were found to be unsuitable for analysis. The reasons for this is that many rings lack an abrupt termination of late wood growth and many have several false bands within the late wood, making determination of the precise ring boundary difficult (Figure 3). With discs it is often possible to trace the circumference of the ring, however, using cores this is not possible. As a result, only 21% of the cores and 100% of the discs from Krakadouw and 30% of the cores and 62% of the discs from Algeria were utilised in the final chronologies. These results indicate that although age determination of *Widdringtonia cedarbergensis* based on ring counts is possible, a high percentage of the wood collected in the field will be unsuitable for dendrochronological purposes. *Widdringtonia cedarbergensis* is an endangered species. Cutting down trees for discs is not a viable option while it is only possible to cross-date a small percentage (20–30%) of all cores. The vegetation in which these trees grow (fynbos) is fire adapted (Le Maitre & Midgley 1992). Trees killed in the regular fires that sweep the mountains can be used to provide the discs necessary for chronology development.

Rainfall in the Cedarberg Mountains is highly variable with mean averages at Algeria (360 mm) being not only more consistent but also as much as three times higher than at Krakadouw (120 mm). The differences in rainfall at these sites are exhibited

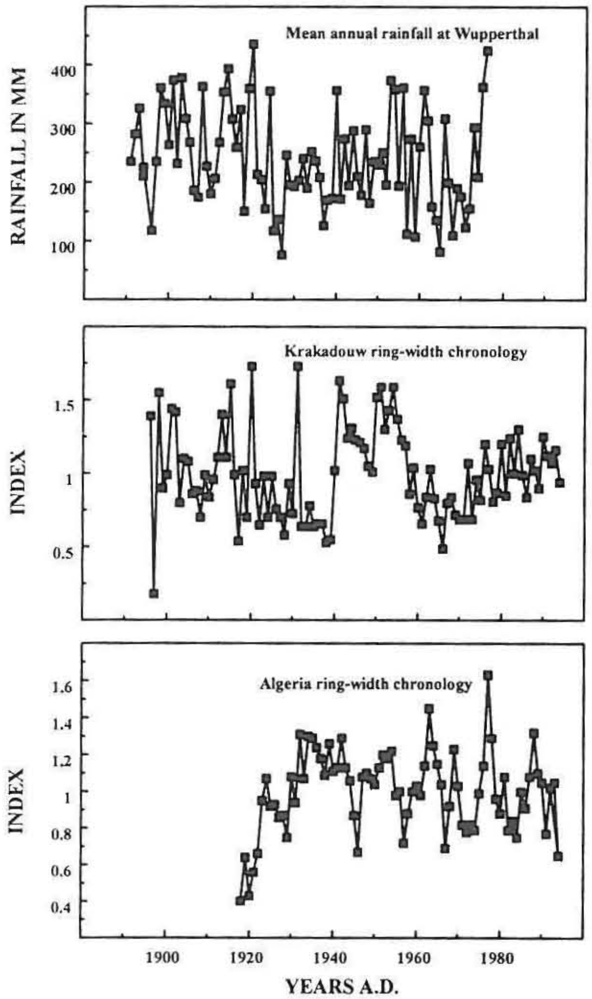

Figure 4 Tree ring chronologies from Krakadouw and Algeria compared with rainfall variation at Wupperthal.

in the responses of the ring widths of the trees. At Krakadouw there is a much higher correlation between rainfall and ring width indices than at either 'Die Bos' or Algeria. However, this response to rainfall only represents 23% of the variation in ring width at Krakadouw and 0.004% at Algeria. While these correlations are significant, they are not sufficiently high for reconstruction of the rainfall record back through time (Zucchini & Hiemstra 1983). Even when only those years with the highest and lowest tree ring indices were compared with the rainfall record, the degree of correspondence did not increase (Figure 4). Using trees from the driest locations at Krakadouw may increase the correlations between rainfall and ring width indices. Such specimens would have to be located on cliff faces or on top of rocky outcrops with very limited means for accessing water.

Acknowledgements

This research was funded by a grant from the Water Research Commission. It would not, however, have been possible without the enthusiastic support of many members of the Laboratory of Tree Ring Research at the University of Arizona especially Malcolm Hughes, Steve Leavitt, Rex Adams and Mark Kaib. Noel Fouten prepared the discs and Clive Booth printed the photomicrograph.

References

COOK, E., BIRD, T., PETERSON, M., BARBETTI, M., BUCKLEY, B., D'ARRIGO, R. & FRANCEY, R. 1992. Climatic change over the last millennium in Tasmania reconstructed firom tree-rings. *Holocene* 2,3: 205–217.

COOK, E.R. 1985. A time series analysis approach to tree-ring standardization. PhD Dissertation, University of Arizona, Tucson.

CURTIS, B.A., TYSON, P.D. & DYER, T.G.J. 1978. Dendrochronological age determination of *Podocarpus falcatus*. *South African Journal of Science* 74: 92–95.

DUNWIDDIE, P.W. & LA MARCHE V.C. Jr. 1980. A climatically responsive tree-ring record from *Widdringtonia cedarbergensis*, Cape Province, South Africa. *Nature* 286: 796–797.

DYER, T.G.J. 1982. Southern Africa. In: Climate from tree rings. eds. M.K. Hughes, P.M. Kelly, J.R. Pilcher, & V.C. La Marche, Jr., pp. 18–21. Cambridge University Press, Cambridge.

HOLMES, R.L. 1983. Computer assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* 43: 69–78.

LARA, A. & VILLALBA, R. 1993. A 3620-year temperature record from *Fitzroya cupressoides* tree rings in southern South America. *Science* 260: 1104–1106.

LE MAITRE, D.C. & MIDGLEY, J.J. 1992. Plant reproductive ecology. In: The Ecology of Fynbos: Nutrients, Fire and Diversity, ed. R.M. Cowling, pp. 134–174. Oxford University Press, Cape Town.

LILLY, M.A. 1977. An assessment of the dendrochronological potential of indigenous tree species in South Africa. Dept. of Geographical and Environmental Studies. University of the Witwatersrand, Occasional Paper N°18.

MCNAUGHTON, I. & TYSON, P.D. 1979. A preliminary assessment of *Podocarpus falcatus* in dendrochronological and dendroclimatological studies in the Witelsbos forest Reserve. *South African Forestry Journal* 111: 29–33.

NORTON, D.A., BRIFFA, K.R. & SALINGER, M.J. 1989. Reconstruction of New Zealand summer temperatures to 1730 A.D. using dendroclimatic techniques. *International Journal of Climatology* 9: 633–644.

ROBINSON, W.J. & EVANS, R. 1980. A microcomputer-based tree-ring measuring system. *Tree-Ring Bulletin* 40: 59–64.

STOKES, M.A. & SMILEY, T.L. 1968. An introduction to tree-ring dating. University Chicago Press, Chicago.

TYSON, P.D. 1986. Climatic change and Variability in Southern Africa. Oxford University Press Cape Town.

ZUCCHINI, W. & HIEMSTRA, L.V.A., 1983. A note on the relationship between annual rainfall and tree ring indices for one site in South Africa. *Water SA*. 9: 153–154.